# Development of a Nanosensor and Instrumentation System for early detection of Lung Disorder using Exhaled Breath

**Synopsis submitted in fulfilment of the requirements for the degree**

**of**

**Doctor of Philosophy**

**in**

**Electronics**

**by**

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**Under the supervision of**

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# Synopsis of the Doctoral Thesis

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| Name of the Student | Pratima Bhat |
| Name of the Research Guide | Prof. Naveen Kumar S K |
| Title of the Ph.D. Thesis | Development of a Nanosensor and Instrumentation system for early detection of Lung disorder using Exhaled Breath |
| Work Place | Department of Studies and Research in Electronics, Mangalore University, Mangalagangotri, konaje-574199. |
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## 1.1 Introduction

The fabrication of new sensing devices using nano-structured semiconducting material is becoming more popular in research in recent years due to its outstanding properties and reduced cost. Sensing devices are useful in applications like leakage of inflammable gas for safety, pollution monitoring, explosive monitoring in chemical industries, air quality investigation, disease monitoring, food technology, etc [1][2]. Expose of toxic, hazardous gases like Nitric Oxide (NO), oxides of carbon (CO, $CO_2$), ammonia ($NH_3$), or Volatile organic compounds (VOCs) such as methane ($CH_4$), toluene, benzene, etc., originated from vehicle emissions, burning of fuels, pesticides or industry wastes into soil, air or water are of deep concern for environment, domestic safety and health sector and thus needs to be continuously monitored [3][4].

In health care sector, gas sensors can be used as a non-invasive tool for early disease diagnosis by analyzing VOCs in the breath. These VOCs are called as breath marker or biomarker, for example acetone is the biomarker for diabetes, ammonia is for kidney related diseases, and Nitric oxide (NO) is for acute asthma, etc. [5] [6] [7].

Many analytical techniques were used for sensing gases like Fourier transform infrared (FTIR) spectroscopy, gas chromatographs (GC), and mass spectrometers (MS) [8][9][10]. But these spectroscopic techniques need sophisticated tools which makes it non-portable, require huge space, complicated statistical tools and trained operating persons, which is laborious and thus can be replaceable with Semiconducting material based gas sensor[11].

Gas sensors using semiconducting metal oxide (SMO) works on the basis of a simple interface, transducer and receptor mechanism. When it associate with oxygen molecules in the air, it acts like a receptor. This interreact mechanism produces a depletion zone across the grain boundary of the sensing layer which affects the resistance of the film layer, depending upon the type of semiconductor and type of gas. This change in the resistance delivers an electrical signal, with a magnitude that is proportional to the concentration of the gas under test. The

adsorption and desorption of gas molecules on the sensing layer results the gas sensing parameters such as sensitivity, response and recovery time, detection limit etc.,[12][13]. Gas sensing properties depend upon oxide material, its microstructure, morphology, electrode-surface interaction and operating temperature [14]. Thin film nanostructure materials like nano-disc, nano-wire, nano-tube, nano-sheets like two-dimension produces high aspect ratio and hence are useful for gas-sensing applications [15].

Among various semiconducting metal oxides (SMO) like $SnO_2$, $TiO_2$, ZnO, $In_2O_3$, $WO_3$, etc., transition metal oxides like ZnO, is a good candidate for gas sensors as their conductivity response is excellent upon gas interaction, shows good response towards oxidative and reducing types of gases and has good sensitivity and selectivity properties [16]. ZnO is preferred due to its excellent chemical and photochemical stability, high-electron communicating features, non-toxicity, biodegradable, ease of synthesis and can easily form hybrid structures with other materials [17][18].

The morphology of the sensing material can be modified by annealing temperature, doping or hybrid structures using functional materials like carbon nanotubes or polymers, which improves oxygen vacancies for gas interaction [19] [20] [21]. The commercial sensors based on thin film semiconductors like $SnO_2$ have shown limitations in reproducibility, stability, sensitivity and selectivity. Also these sensor works at high operating temperatures (200℃ - 500℃) to increase the rate of the reaction. Such materials have limited surface-to-volume ratio determines a limited gas response to low concentration of tested gases and hence requires operation at elevated temperatures to reach a desired gas response. This is usually accomplished by incorporating a heater into the sensor. Room temperature based sensors are high in demand as they explore materials for development of low power devices [22].

Synthesis and deposition of sensing layer as a thin film on a substrate can be done by methods like physical vapor deposition (PVD), chemical vapor deposition (CVD), sputtering, sol-gel, spin coating, spray coating etc. Sol-gel

technique is comparatively easy and inexpensive technique which yields good quality of nanostructures [23]. The other techniques like spray coating, dip coating, drop-casting, doctor's blade method can be used but require well dispersed and soluble solutions. Drop cast and doctor's blade method produces thick film coating. Spray coating is useful only when the sample is in soluble solution form [24].

The electrode deposition and its integration plays an important role in the fabrication of sensor. The Interdigitated electrode geometry, with narrow finger gap of electrode reduces the free charge losses by shortening the current path and thus reduces the resistivity of the material [25] [26].

Sensor fabrication by deposition of sensing film on a flexible substrate have the advantage of bending, light weight, robustness, wearable, proximity to human body (skin) and easy electrical wire bounds to make an external circuit connections [27] .

The work in the thesis can be broadly divided into two major parts namely (i) fabrication of gas sensor for sensing VOC responsible for early diagnosis of lung cancer and (ii) design and development of gas chamber along with instrumentation circuit to test and monitor the VOC using fabricated gas sensor.

The first part of the work is focused on the fabrication of ZnO and ZnO/f-MWCNT hybrid composite as sensing layer on a flexible interdigitated electrode to sense 1-butanol VOC which can be considered as a prominent biomarker for early detection of lung cancer.

Second part of the work is focused on the development of custom designed portable gas chamber and signal processing circuit to analyse and test the fabricated gas sensor towards 1-butanol VOC.

## 1.2 Objectives

- The identification of VOC (biomarker) for Lung cancer.
    - 1-butanol VOC at ppm level
- Synthesis and characterization of sensing material
    - ZnO as thin film layer deposited on glass and flexible substrate using spin coating technique.
    - Effect of annealing temperature on micro structure, morphology and optical studies of ZnO thin film.
    - ZnO/f-MWCNT hybrid composite as thin film layer deposited on glass and flexible substrate using spin coating.
    - Characterization of ZnO and ZnO/f-MWCNT thin film
- Sensor fabrication on flexible Teflon substrate and testing the gas analyte in gas chamber
    - Design of mask for IDE (Interdigitated electrode) structure.
    - IDE structure development on different substrates (glass and flexible Teflon substrate).
    - Fabrication of ZnO gas sensor towards different VOC– ethanol, acetone, toluene, xylene at ppm levels.
    - Fabrication of ZnO and ZnO/f-MWCNT sensor for sensing different ppm levels of 1-butanol VOC.
- Development of portable gas chamber and instrumentation circuit
    - ZnO sensor is tested towards 1-butanol VOC in a portable gas chamber.
    - Evaluation of sensitivity, response, and recovery time of fabricated gas sensor with signal conditioning circuit and instrumentation amplifier in the gas chamber.

## 1.3 Thesis Organization

The thesis focuses on the fabrication of semiconducting metal oxide based-nanosensor for early diagnosis of lung disorder in a custom-designed gas chamber unit with instrumentation circuits. The thesis is structured into seven chapters. The workflow is explained in each chapter.

**Chapter 1: Introduction.** In this chapter, we introduce gas sensors, the need for sensors as a non-invasive technique in medical diagnostic applications. VOC identification for lung disorder and the material for sensing the identified VOC is done through literature survey and the problem identification is stated and the objectives of the research work are formulated. The aim and scope of the thesis are outlined.

**Chapter 2: Experimental methods.** In this chapter, methods for sensor fabrication are discussed which includes (i) the synthesis and deposition of semiconducting material as a sensing layer and (ii) electrode formation. With the help of a flow chart, synthesis and deposition steps of ZnO and ZnO/f-MWCNT hybrid composite as a sensing layer and the deposition of interdigitated electrodes (IDE) are described. The fabrication of sensor for testing different VOCs is elaborated along with optimized parameters. Further, the characterization techniques and tools are discussed. With a neat block diagram, development of a gas chamber with associated circuitry is described.

**Chapter 3: Synthesis, deposition and characterization of ZnO and ZnO/f-MWCNT hybrid composite**: In this chapter, we study the preparation of the sensing layer for the gas sensor. Synthesis of ZnO nanoparticles and ZnO/f-MWCNT hybrid composite using the wet chemical synthesis method is discussed. Two different mass percentage of MWCNT composites were synthesized. The deposition of all three thin films – ZnO, ZnM1 (0.05 wt. % of MWCNT/ZnO) and ZnM2 (1 wt. % of MWCNT/ZnO) using spin coating is discussed on glass substrate. Various characterization studies of the three samples like microstructure, surface morphology, chemical composition, chemical bonding, and optical parameters are analyzed. The variation in the

lattice parameters of ZnO and its hybrid composite from XRD are discussed in Table *1*, and the microstructure parameters of the samples are given in Table *2*.

**Table 1: Lattice parameters from XRD**

| Sample | Preferred orientation (101) | | Lattice parameters (nm) | | | |
|---|---|---|---|---|---|---|
| | Brag's Angle (2θ) | FWHM $\beta_d$ | a=b | c | c/a | V($nm^3$) |
| ZnO | 36.36 | 0.197 | 0.2850 | 0.4942 | 1.731 | 34.744 |
| ZnM1 | 36.49 | 0.205 | 0.2840 | 0.4919 | 1.732 | 34.359 |
| ZnM2 | 36.50 | 0.208 | 0.2848 | 0.4915 | 1.731 | 34.283 |

**Table 2: Microstructural parameters from XRD**

| Samples | Brag's Angel 2θ | Crystallite size D (nm) | Tensile Strain (ε) | Dislocation density δ(line/$m^2$) | Texture Coefficient ($T_C$) |
|---|---|---|---|---|---|
| **Pure ZnO** | 36.36 | 73.83 | $4.915 \times 10^{-2}$ | $1.836 \times 10^{-4}$ | 1.678 |
| **ZnM1** | 36.49 | 71.2 | $5.09 \times 10^{-2}$ | $1.972 \times 10^{-4}$ | 0.776 |
| **ZnM2** | 36.50 | 70.16 | $4.97 \times 10^{-}$ | $2.03 \times 10^{-4}$ | 0.34 |

Uniform hexagonal disc structure of ZnO were obtained from FESEM analysis and were transformed into hollow ring like structure upon adding MWCNT. Composite samples have the thin fibers of MWCNT in between hexagonal ZnO discs which helps in joining the ZnO nanodisc. Optical studies shows the direct energy bandgap of ZnO sample is 3.12 eV, calculated from Tauc's plot and it is decreased to 3.0 eV and 2.97 eV for ZnM1 and ZnM2 sample respectively. With an increase in MWCNT concentration, carrier concentration increases, which enhances the states within the conduction band pushing the Fermi level inside the conduction band, leading to the contraction of the energy bandgap. FTIR analysis confirms the stretch for ZnO at low frequency at 428 $cm^{-1}$, 1348 $cm^{-1}$ peak indicted C=C stretching of carboxylic group, 2343 $cm^{-1}$ indicated C-H groups, peaks at 3783 $cm^{-1}$ indicate the O-H group. C-V analysis confirms the semiconducting nature of the sensing layer and the studies show that the samples acts like a tuning capacitor.

**Chapter 4: Effect of annealing temperature on ZnO thin film and its application towards Nitric Oxide sensing.** In this chapter, as deposited zinc oxide (ZnO) thin film on a glass substrate is annealed at various temperatures from 200℃ to 700℃ in an ambient atmosphere in a muffle furnace for one hour. The effect of annealing temperature on the microstructure, surface morphology, and optical properties of ZnO thin films is discussed. Annealed films have shown polycrystalline nature with hexagonal wurtzite phase of ZnO. The grain size and the crystalline nature of the film have improved with an increase in annealing temperature. FESEM results showed a transformation into two-dimensional flower-like structure, enhancing the sensing property of the film with improved surface area for gas adsorption as compared to the as-prepared ZnO thin film. Optical band gaps were determined using Tauc's plot.

The gas sensing studies were carried out towards Nitric oxide gas by fabricating a ZnO sensor with sliver paste as a top electrode on different substrate is shown Figure 1.

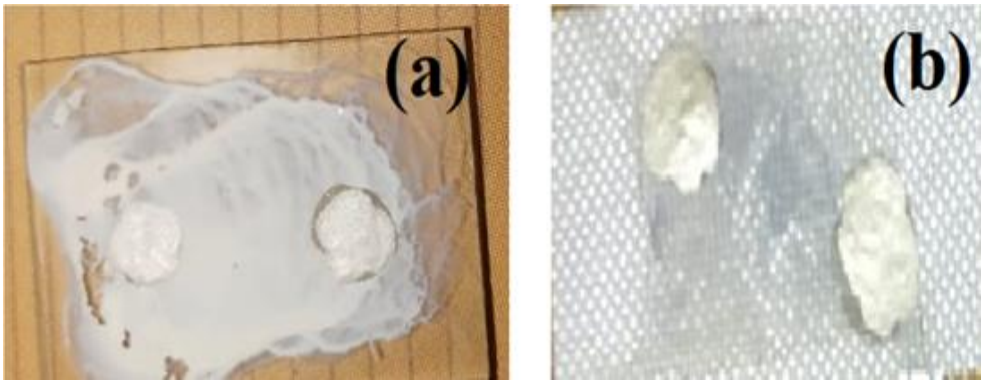


**Figure 1: ZnO thin film sensor developed on (a) glass substrate (b) flexible Teflon cloth**

The annealed ZnO sensors are studied towards nitric oxide gas at a concentration level of 2.75 ppm at an operating temperature of $150^0$C in a gas chamber with a source meter Keithley 2450. The sensitivity curve and response and recovery times are measured from the transient resistance response, shown in Figure 2.

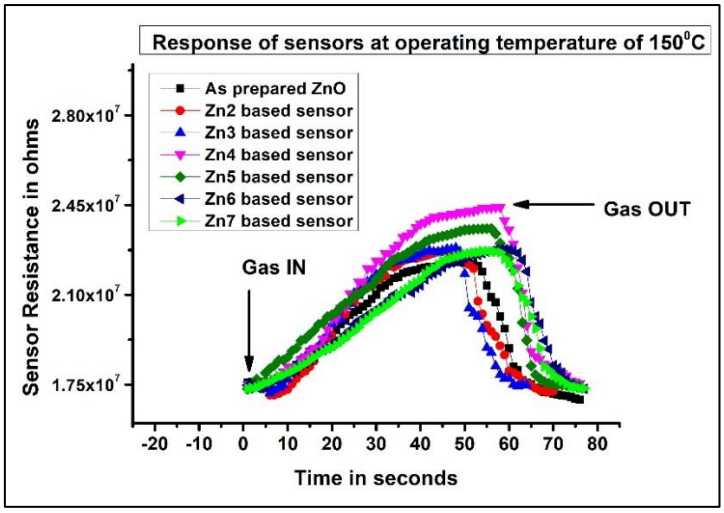


**Figure 2 : Response of annealed ZnO sensors at 150 ℃ towards NO gas**

At an operating temperature of 150℃, the Zn4 sensor has shown a sensitivity of 1.4 with response and recovery time of 52 sec and 19 seconds respectively. The sensitivity and response time of Zn4 sensor is studied at different operating temperature from 150℃ to 350℃ and the sensitivity was high at operating temperature of 300℃ as shown in Figure 3.

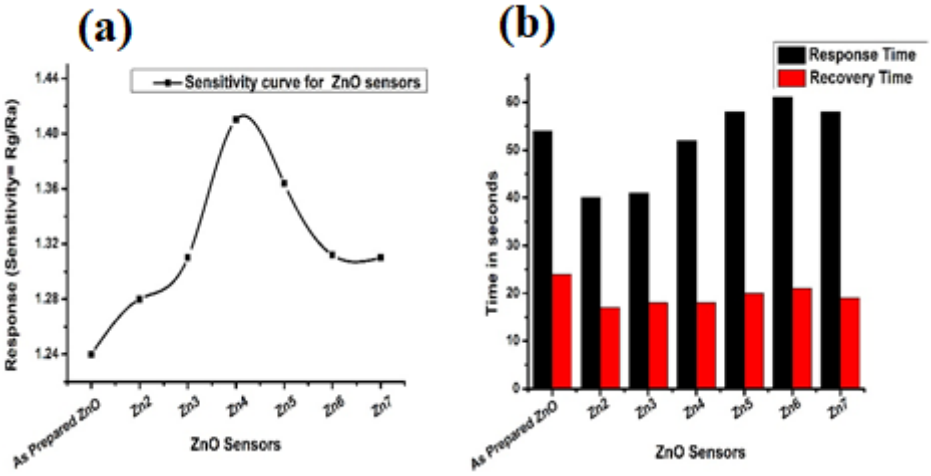


**Figure 3: (a) Sensitivity (b) Response and Recovery times of annealed ZnO sensors**

**Chapter 5: Fabrication of IDE-based flexible sensor for 1-butanol VOC sensing.** In this chapter, we describe the development of an interdigitated electrode (IDE) using CAD designed mask on various substrates. The mask is aligned and held over the substrate and clipped all over the sides with Kapton

tape that can withstand temperatures up to 700°C and loaded in the thermal evaporation unit for deposition of aluminum as shown in Figure *4*.

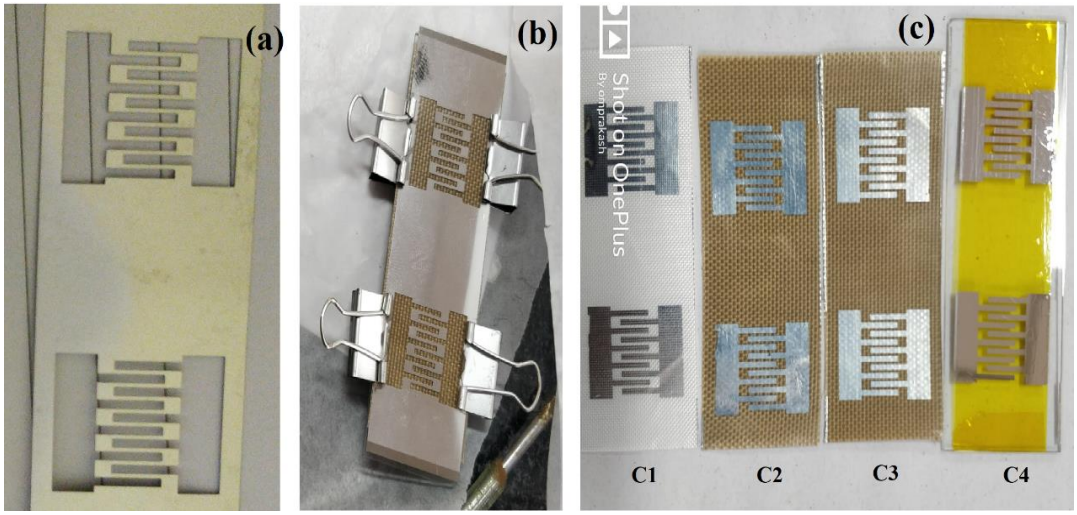


**Figure 4**: **(a) Stainless steel Mask of IDE (b) Substrate loaded with mask (c) IDE patterned on different substrates**

The advantages of deposition of IDE as the bottom electrode, on flexible Teflon substrate, are discussed for sensor fabrication. ZnO film and ZnO/f-MWCNT composite films are deposited over this IDE using spin coating technique as shown in Figure *5* (b) and Figure 5(c) respectively.

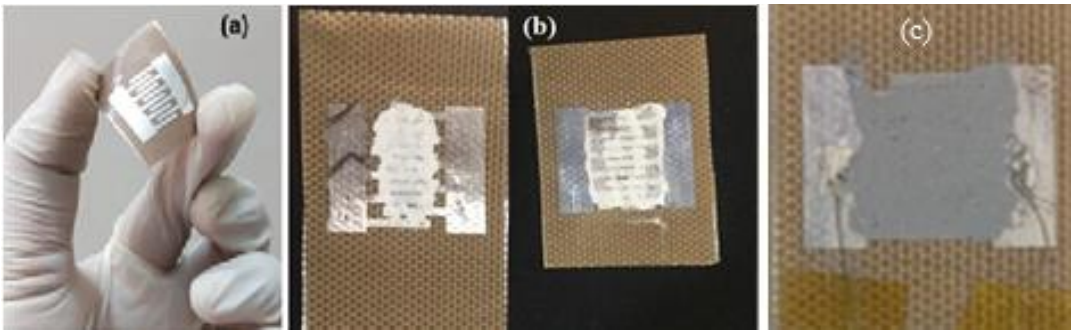


**Figure 5**: **(a) Bending flexibility of Teflon substrate; (b) coating of ZnO on Teflon (c) coting of ZnO/f-MWCNT on Teflon**

The fabricated ZnO sensor is characterized for thickness, roughness and electrical studies and further tested for different VOCs such as acetone, 1-butanol, ethanol, xylene, and toluene at 50 ppm level and the transient response is shown in Figure 6.

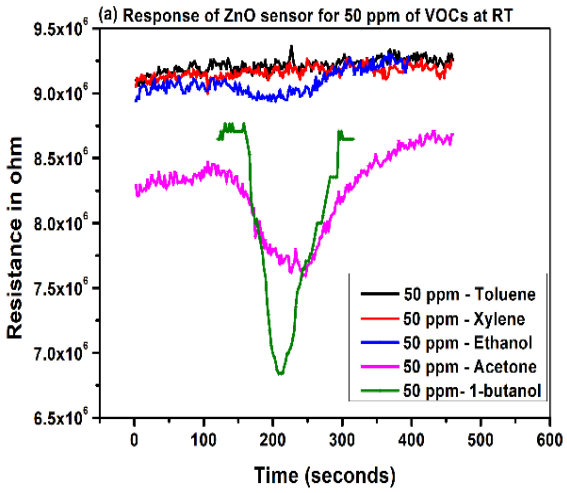


**Figure 6: Transient resistance response of ZnO sensor at RT, towards 50 ppm of VOCs**

Relative response (in %) obtained are ~ 0.99 for xylene ($C_8H_{10}$), ~ 1.01 for toluene ($C_7H_8$), ~ 1.75 for ethanol ($C_2H_4O$), ~ 8.7 for acetone ($C_3H_6O$) and ~ 28.6 for 1-butanol ($C_4H_{10}O$). The sensor is highly selective towards 1- butanol VOC. The parameters like relative sensitivity, response, and recovery time are tabulated in Table 3.

**Table 3: Response of ZnO sensor towards VOCs (50 ppm)**

| VOCs | Relative sensitivity S (%) | Response time (seconds) | Recovery time (seconds) |
|---|---|---|---|
| Xylene | 0.99 | 109 | 162 |
| Toluene | 1.01 | 106 | 159 |
| Ethanol | 1.75 | 88 | 108 |
| Acetone | 8.7 | 80 | 97 |
| 1-butanol | 28.6 | 60 | 74 |

1-butanol VOC sensing studies are carried out at different concentration level from 50 ppm to 500 ppm levels using ZnO and ZnO/f-MWCNT composite film sensors. Various parameters like sensitivity, response time, and recovery time of all three sensors –ZnO, ZnM1 and ZnM2 towards different ppm levels of 1-butanol are calculated and tabulated in Table 4. These sensing studies are done at room temperature (27°C) using Keithley 6517B, USA.

**Table 4: Study of sensing parameters of ZnO, ZnM1 and ZnM2 sensors towards 1-butanol VOC**

| Concentration of 1-butanol | Sensing parameters | ZnO sensor | ZnM1 sensor | ZnM2 sensor |
|---|---|---|---|---|
| 50 ppm | S | 1.28 | 1.13 | 1.07 |
| | Rs (sec) | 60 | 30 | 20 |
| | Rr (sec) | 80 | 50 | 30 |
| 100ppm | S | 1.89 | 1.35 | 1.16 |
| | Rs (sec) | 30 | 25 | 18 |
| | Rr (sec) | 35 | 32 | 30 |
| 200ppm | S | 3.27 | 1.88 | 1.87 |
| | Rs (sec) | 35 | 30 | 26 |
| | Rr (sec) | 40 | 40 | 38 |
| 500ppm | S | 5.01 | 2.75 | 2.57 |
| | Rs (sec) | 50 | 40 | 30 |
| | Rr (sec) | 85 | 50 | 40 |

**Note: S-Sensitivity; Rs – Response time; Rr-Recovery time.**

It is observed that, the ZnO film sensor has shown the highest sensitivity compared to composite sensors, whereas the composite sensors ZnM1 and ZnM2 have shown the faster response and recovery time compared to pure ZnO films. The quick response time of 10 sec and recovery time of 18 sec is achieved by ZnM2 composite sensor towards 100 ppm of 1-butanol. This shows that with the addition of MWCNT, the rate of adsorption of the sensor has improved, which has reflected in quick response and recovery time. A real time sensor highly needs faster response and recovery time, as the sensitivity can be enhanced by connecting a suitable hardware to the sensor output. As a medical diagnostic tool, the sensor should have high sensititvity. Thus the fabricated ZnO sensor can be used as a medical diagnostic tool.

**Chapter 6: Design and development of portable gas chamber and instrumentation circuit for performance testing.** In this chapter, a novel portable gas chamber is designed and constructed for VOC detection. The proposed test chamber allows for both static and dynamic measurements of gas/VOC is shown in Figure 7. The functionality of each component in the gas chamber along with its parameters is described in Table 5.

**Figure 7: (a) CAD design of proposed gas chamber (b) Developed gas chamber**

**Table 5: Components of Gas chamber –Functionality and Parameters**

| Sl.no | Components | Functionality | Parameters |
|---|---|---|---|
| 1. | Chamber | It's thermally conducting and electrically insulator, not reactive with any gas. | Diameter -21 cm , Capacity- 5litre volume, Material- Indallium. |
| 2. | Specimen holder | Holds the sensor (specimen film) | Polished steel test bench, Dimention-70X 50 X 20 mm |
| 3. | Specimen heater pad | The heater pad dispenses the required temperature to the specimen film. | Tubular pencil heater - 2 Nos. Diameter - 8mm, length-60 mm, and capacity -70 watt |
| 4. | Solvent holder | Holds the solvent of the target VOC. | Polished curved crucible, Size-50 X 50 X 10 mm. |
| 5. | Solvent heater (evaporator) pad | The heater pad is used to evaporate the target solvent. | Tubular pencil heater-2 Nos. Diameter -8mm and Length-60 mm, Capacity -70 watt |
| 6. | Thermostat_1 | Detects and maintains the sensor's operating temperature. | 6 mm size (Elcon Make) 30°C to 300°C. |
| 7. | Thermostat_2 | Maintains the required temperature to evaporate the solvent into its vapor. | 6 mm size (Elcon Make) 30°C to 300°C. |
| 8. | Control Panel | Housing the thermostats and ON/OFF power switch. | MS sheet fabricated box |
| 9. | Rotary switches | Sets the required temperature for thermostat_1 and thermostat_2 | Range - 0°C to 300 °C Range - 0°C to 300 °C. |
| 10. | DC Voltage testing terminals (Electrodes) | Placed on Interdigitated Electrode of the sensor, to measure the variations in the resistance of sensing material. | Adjustable rod of 8mm diameter insulated outside connected to the outer brass bolt assembly |
| 11. | PU tube_1 | Let in the gas from the cylinder, act as a flow controller. | 6 mm diameter with an open and closing valve |
| 12. | PU tube_2 | Let out the gas from the chamber | 6 mm diameter with an open and closing valve |

The fabricated flexible IDE zinc oxide sensor is tested for 1-butanol VOC at different ppm levels.

The sensor resistance variation is measured in terms of voltage with the help of a signal processing circuit and an instrumentation amplifier as shown in Figure 8.

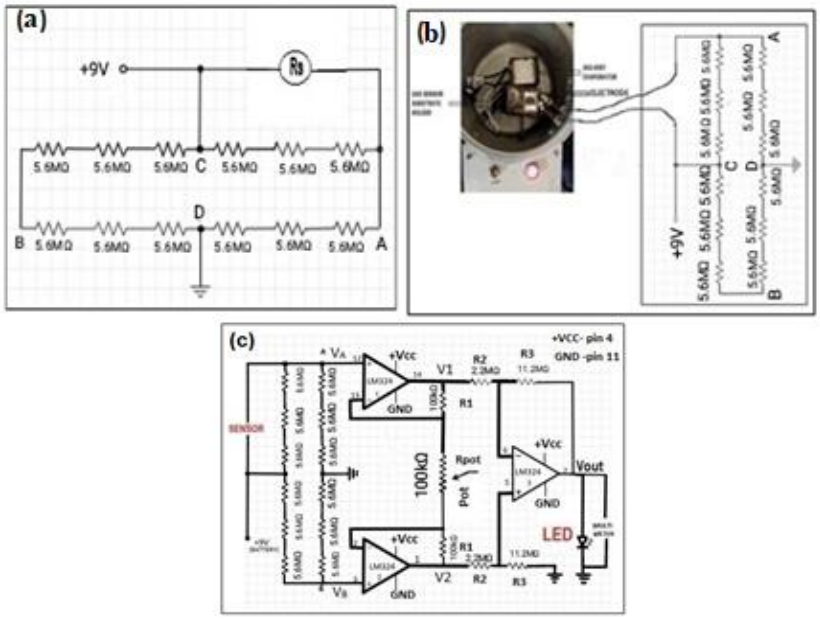


**Figure 8**: **(a) Wheatstone bridge circuit with shunt resistance (Rs) (b) Sensor connection from the chamber to the circuit (c) Signal conditioning circuit connected to Instrumentation Amplifier**.

The sensing results of the ZnO sensor towards 100 ppm and 50 ppm of 1-butanol VOC are studied in the custom-designed gas chamber and the transient voltage response is shown in Figure 9.

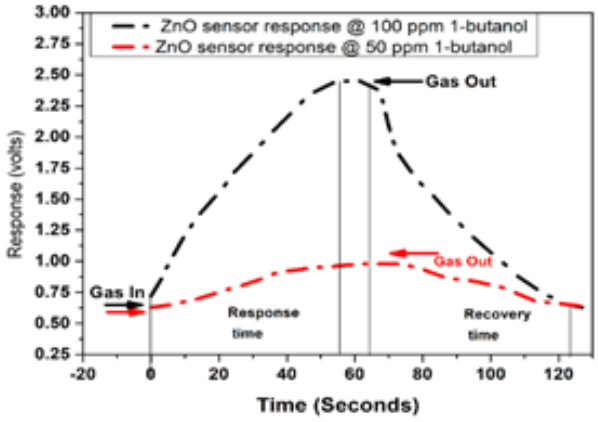


**Figure 9**: **Transient voltage response of ZnO sensor at ppm levels of 1-butanol**

The parameters–sensitivity, response time, and recovery time of ZnO sensor are studied and tabulated in Table *1*Table 6.

**Table 6: Sensing parameters of ZnO sensor towards 1-butanol VOC (from the custom-designed gas chamber)**

| Concentration of 1butanol VOC | Sensitivity (S) | Response time (seconds) | Recovery time (seconds) |
|---|---|---|---|
| 100 ppm | 3.28 | 55 | 60 |
| 50 ppm | 1.23 | 62 | 70 |

The designed gas chamber is low cost, portable and simple in operation when compared with the present-day laboratory setup. The designed gas chamber is also incorporated with an electronic circuit to acquire and process signals obtained by the sensor. The tabulated results nearly match with that of the previous experimental results which were carried out in a laboratory setup with Keithley.

**Chapter 7: Summary and future Work.** The fabrication of semiconducting metal oxide–based ZnO gas sensor for sensing 1-butanol VOC is summarized and tested in a custom designed portable gas chamber unit with instrumentation circuit. The sensor fabrication including the synthesis and deposition of the material on substrate is elaborated and its different characterization properties are summarized. Different ways to improve the response of the sensor is explored such as by observing the effect of annealing temperature, adding other functional materials like MWCNT added to ZnO with different weight percentage, forming a ZnO/f-MWCNT hybrid composites. The sensor performance is studied by developing interdigitated electrodes for stable integration with the instrumentation system. The fabricated ZnO sensors were tested for various toxic VOCs such as ethanol, acetone, xylene, toluene, and 1-butanol, which are hazardous for the lungs. The future scope of the work is to modify the sensor to achieve better sensing results at lower ppm levels at room temperature by adding ZnO with other noble metals or polymers or metal oxides. The sensor dimensions also can be modified to lower areas to make it more compact to use in micro-chip systems. The custom-designed gas chamber system discussed in the present work can be made more interactive by incorporating units like a built-in mini fan which ensures uniformity of gas concentration throughout the chamber, a microcontroller based temperature controller for

substrate holder and solvent holder, a heater that can be a ramp heater of compact size, vacuum creation pump through an inlet valve, a microcontroller operated instrumentation display attached to it to evolve as a point of care system.

**Notable outcomes of the Research Work:**

A. List of Papers published in Journals

1. Pratima Bhat, Dr. Uma Ullas Pradhan and, Naveen Kumar. S.K., "Sensor Applications of Metal Oxide Semiconductor Nanoparticles for Breath Analysis: A Review", Pariprashna Academic Journal, Jain University, 2, pp. 330-337, February 2016.
2. Pratima Bhat, Dr. Uma Ullas Pradhan and, Naveen Kumar. S.K., "Synthesis and Characterization of ZnO Nano Discs Using Wet Chemical Method for Sensing Applications", Materials today Proceedings, 5 Issue 4, Part 3, 2018, Pages 10763-10770. https://doi.org/10.1016/j.matpr.2017.12.360
3. Pratima Bhat, Dr. Naveen Kumar. S. K, P. Nagaraju, "Synthesis and Characterization of ZnO-MWCNT nanocomposites for 1-butanol Sensing Application at Room Temperature", Physica B Condensed Matter, 570, 139-147 - October 2019. https://doi.org/10.1016/j.physb.2019.06.008
4. Pratima Bhat, Sindhugatta Kalappa Naveen Kumar, P Nagaraju, "Effect of annealing temperature on microstructure, optical, morphology and gas sensing characterization of nano disc ZnO thin films", AIP Conference Proceedings 2244, 110008 (2020). https://doi.org/10.1063/5.0009500
5. Pratima Bhat, Naveen Kumar S.K, and P. Nagaraju, "Fabrication of ultrasensitive hexagonal disc structured ZnO thin film sensor to trace nitric oxide", J. of Asian Ceramic Societies, 2020. https://doi.org/10.1080/21870764.2020.1848036
6. Pratima Bhat, and S. K. Naveen Kumar, "Evaluation of IDE-based flexible thin film ZnO sensor for VOC sensing in a custom designed gas chamber at

room temperature", Journal of Material Science: Material in Electronics, 33, 1529-1541 (2022). https://doi.org/10.1007/s10854-021-07664-x

7. Pratima Bhat and S. K. Naveen Kumar, "Real-time detection of 1-butanol VOC in an indigenously developed Gas chamber", IOP Conference Series: Materials Science and Engineering, 1221, 012005 2022. https://10.1088/1757-899X/1221/1/012005

B. List of Conferences attended

1. Pratima Bhat, Dr. Uma Ullas Pradhan and, Naveen Kumar. S.K, **"**Sensor Applications of Metal Oxide Semiconductor Nanoparticles for Breath Analysis: A Review", National Conference "Recent Trends in Physical Sciences-RTPS-16", held at School of Graduate Studies, Jain University, J.C. Road, Bangalore on 25th-26th February 2016.
2. Pratima Bhat, Dr. Uma Ullas Pradhan and, Naveen Kumar. S.K, "Synthesis and Characterization of ZnO Nano Disc using Wet Chemical Method for Sensing Applications", International Conference on Large Area Flexible Microelectronics (ILAFM 2016) at R. V. Engineering College, Bangalore, 20th-22nd December, 2016.
3. Pratima Bhat, Dr. Uma Ullas Pradhan and, Naveen Kumar. S.K, "Structural Modulation of ZnO Nano disc after Annealing at Various temperatures" in International Conference on Nano Science and Nanotechnology (ICONN' 2017) on 9, 10,11th August 2017 at S.R.M University Chennai, India, 2017.
4. Pratima Bhat, Naveen Kumar. S.K and P. Nagaraju, "Effect of Annealing Temperature on Microstructure, Optical, Electrical and Gas sensing characterization of Nano Disc ZnO Thin Film", in International Conference on Physics of Materials & Nanotechnology, (ICPN-2019) at Mangalore University during September 19-21, 2019.

5. Pratima Bhat, and Naveen Kumar. S.K, “Semiconducting Metal Oxide Gas Sensor for Medical Diagnostics”, in the National Conference on Materials Physics 2020, on 5th and 6th November 2020, organized by School of Applied Sciences, Department of Physics, Reva University, Bangalore.
6. Pratima Bhat, and Naveen Kumar. S.K, “Performance Testing of ZnO/MWCNT composite based flexible gas sensor in a Custom designed Gas chamber”, in Second International E-Conference on Physics of Materials & Nanotechnology (ICPN 21) at Mangalore University during 28$^{th}$ -30$^{th}$ October 2021.

C. List of Paper communicated to Journals

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